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Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: A transdisciplinary approach

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ABSTRACT

Rainfed agro-ecosystems, the purported grey patches untouched by the Green Revolution or most technological advances, occupy a prominent position in Indian agriculture. Cropping intensities and crop yields are low and unstable in these areas due to unpredictable patterns of rainfall, a host of biotic and abiotic stresses and adherence to traditional farm practices. This precarious food security situation is especially dangerous in the central Indian tribal belt (also known as the poverty belt) which is a typical rainfed area dominated by tribal communities. More than 90% of the tribal people are totally dependent on agriculture and produce much of what they eat. Small land holdings and their low productivity, along with uncertainties in rainfall patterns, increases economic and social risks for these farmers. With degraded soils and unreliable weather patterns, return on investment is uncertain and likely to be much lower overall than under irrigated conditions with better soils. Under such conditions, one approach to achieve improved crop production is to minimize soil and other natural resource degradation by adopting a set of crop-nutrient-water-land system management practices, such as conservation agriculture (CA). To assess the effect of introduced technology under local ecological and socio-economic conditions, the study focused on two ecosystem services: a) provisional, and b) regulatory through five treatments consisting of farmers' traditional practice (FP) which was conventional tillage with broadcast of local variety maize (*Zea mays* L.); and four CA treatments viz., conventional tillage with sole cropped maize using line sowing of the improved maize cultivar 'Nilesh' (CT-M); conventional tillage with maize intercropped with the improved cowpea (*Vigna unguiculata* L. cultivar 'Hariyalli Bush') (CT-M + C); reduced tillage with sole cropped maize (MT-M); and reduced tillage with maize + cowpea (MT-M + C). After harvest of maize and cowpea, mustard was planted as a post rainy season crop and all the mustard plant residues were returned to their respective plots as residue cover except FP. Under provisional ecosystem services, performance of CA on crop yield, and profitability was assessed through maize equivalent yield and partial budget analysis, respectively. Results showed that reduced tillage combined with maize-cowpea intercropping (MT-M + C) followed by mustard residue retention had higher system productivity and net benefits, an increase of 200% and 230%, respectively over FP. Under regulatory ecosystem services, the soil quality was assessed through calculation of soil quality index (SQI) which was highest under MT-M + C followed by mustard residue retention and lowest under farmers' practices. In terms of CA treatment preference, 35% of the farmers indicated a strong preference for MT-M + C compared to 14% for FP. Combined, these results clearly demonstrate the potential of CA to simultaneously increase yield, diversify crop production and improve soil quality which should support a move towards sustainable intensification of crop production to improve future household income and food security. Additionally, using a transdisciplinary approach fully engaged all stakeholders in co-designing the CA treatments appropriate for the farmers and local environmental conditions leading to significant impacts on economic livelihoods, environmental sustainability and food security.

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1. Introduction

Food security has become increasingly important globally as well as on domestic fronts as global supply, income growth and access is not keeping pace with increasing population in developing countries. Rapid population growth and economic development severely degrades

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the environment through industrialization and expanding of agricultural production into marginal lands. Increasing resource degradation problems such as groundwater depletion, water logging, salinization, soil erosion, loss of biodiversity and invasive species further add to food security challenges (Oliver and Gregory, 2015). In many developing countries like India, food security of the poor will be at risk, as they would face more severe resource and economic constraints due to the above world average population growth and limited arable land. In certain regions of India, like Bihar and Odisha, low agricultural productivity and output, and high poverty rates leave millions, especially those in rural areas, undernourished (Kumar, 2003). The situation is further complicated by decreasing per capita availability of arable land and slow climate change adaptation, which will lower food supply, compounding the challenge of meeting food demand. While climate change may affect the entire world, its impact especially in the rainfed regions of India is more severe because of the dependency of the majority of the people in the region. Rainfed agriculture in India currently accounts for about two-thirds of the total cropped area and nearly half of the total value of agricultural output (Roul et al., 2015). Nearly half of all food grains are grown under rainfed conditions, and hundreds of millions of the rural poor depend on rainfed agriculture as the primary source of their livelihood. Low-input subsistent agriculture in these regions is generally coupled with reduced crop yield and degrading soil conditions. Excessive and inappropriate tillage increases soil degradation and erosion (Cerda et al., 2009), reducing soil productivity and soil organic carbon (Lal, 2004). Thus, agricultural intensification is needed in these regions without further degrading the natural resource base. Furthermore, in the Indian context, average farm size is very small and average household member size is large, with poverty and food insecurity prevalent among small land-holders (Pradhan et al., 2015). Therefore, introduction and implementation of a new agricultural production system should be viewed in the context of enhancing farm productivity, environmental quality and profitability of agriculture while also improving household food and nutritional security.

Food security in India is linked to poverty and sustainability. With the country unable to lower the population growth rate to below 1% per annum, poverty remains an issue. Low caloric intake, poor health, low agricultural productivity and low income are perennial forces in the vicious poverty cycle in India (Varadharajan et al., 2013). The issue is not only the availability of food but of its affordability by vulnerable populations in adequate quantity and quality. It is not a question of whether we can increase food production to meet the needs of the rising population, but whether we can do so in a sustainable manner. It is imperative to develop a long-term strategy that would reduce the vulnerability of the farming community and sustainably intensify agricultural productivity while minimizing the degradation of land and natural resources being used.

Therefore in order to ensure food security on a sustainable basis, a suitable cropping system and land use needs to be implemented and adopted, based on principles to restrict land degradation and conserve the natural resource base as well as increase food and nutritional security through crop diversification and optimal rotation. Among many sustainable cropping systems available, conservation agriculture (CA) is the one that can reverse soil degradation, improve crop production, and enhance the socio-economic condition of small land-holder farmers.

The goal of this study was to identify entry points for improvement of farmers' economic livelihoods through conservation agriculture (CA) in the face of stresses caused by human activities and climate. Specifically, the objectives were to:

1. Evaluate the effect of CA on system productivity and profitability;
2. Evaluate the effect of CA on soil quality;
3. Compare farmer preferences before and after practicing CA to quantify the impacts of on farm action research; and
4. Provide recommendations for stakeholders regarding CA suitability.

2. Why a transdisciplinary approach?

Conservation agriculture strategies and practices have been developed and promoted to reduce risk and improve natural resource conditions such as soil quality, as well as address the combination of low yields, production risks and poor natural resource conditions typically seen in developing areas in Africa and south Asia (Stevenson et al., 2014). CA embodies three main principles: reduced or zero soil disturbance, permanent organic soil cover to reduce soil loss, and crop diversification (FAO, 2013). Currently, CA is being practiced on over 125 million hectares world-wide (Friedrich et al., 2012) and has several reports of reduced production costs, improved water use efficiency, and sustained or increased crop productivity across the globe (Hobbs, 2007; Erenstein et al., 2008; Govaerts et al., 2009; Kassam et al., 2009; Wall, 2009; Thierfelder and Wall, 2009, 2010). In addition, there are reports of erosion control and soil water conservation from implementation of CA (Scopel et al., 2005; Hobbs et al., 2008). Crop diversification with intercropping and rotation improve the nutritional security of the farm households and reduces the risk of total crop failure in unfavorable or erratic weather (FAO, 2013). Labor requirements can be reduced by about 50% for male-driven work of soil tillage but CA can increase female-driven work of weeding (Bishop-Sambrook, 2003).

Despite the documented benefits, the broad applicability of CA to diverse cropping systems around the globe remains contested (Pittelkow et al., 2015; Giller et al., 2009). Furthermore, implementation and adoption of all the three principles of CA in resource poor and vulnerable smallholder farming systems face various issues and challenges, most notably the retention of crop residues due to its strong competition as livestock feed (Giller et al., 2009). Considering various arguments on justifying the implementation of CA, it must obviously be adapted to local agro-ecological conditions and farmer capabilities and preferences. CA is best conceptualized as an integrated production system that is universally applicable but must be locally adapted. Careful consideration of farmer capabilities and preferences is just as important as understanding the production capabilities of the agro-ecological system. Therefore, successful introduction of CA depends upon adapting and tailoring the basic CA principles to the local context.

In order to enhance and promote CA adoption, a transdisciplinary approach was undertaken to evaluate CA in the rainfed uplands of Odisha, India. A transdisciplinary approach is arguably superior for the introduction of CA technology to smallholder farmers in India as it involves complex human and natural systems. The transdisciplinary approach attempts to embody scientific knowledge that is created and assimilated by different disciplines while engaging multiple stakeholders for their inputs in the co-design and implementation of field experiments and demonstrations. This approach builds strong partnerships among researchers, farmers, communities and global audiences, facilitating greater adoption of innovative technologies, and achieving sustainable outcomes. The framework to smoothly transition from CA production system creation to sustainable outcomes involves four stages (Table 1). The first stage involves co-design and research definition of CA. Interdisciplinary researchers engaged farmers, villagers, and local universities and extension/NGO personnel to explain CA technology and potential outcomes to farming systems. Potential experimental designs to evaluate CA production systems were determined after multiple engagements with stakeholders on local practices and cropping preferences. Experimental outcome indicators were developed collaboratively. The second stage was data collection. Once CA treatments were determined from stage 1, an experimental design for treatment assessment was developed. Farmers and villagers were provided with training on implementing; managing the field experiments, and the universities and NGO collected the data. The district government and funding agencies were informed of the experiments. The third stage encompassed data analysis, determination of relevancy and interpretation of outcomes. After data analysis by researchers, the relevancy of the results was discussed and interpreted among the

Table 1
A transdisciplinary framework for the introduction of conservation agriculture treatment to farmers in India.

Stages	Engagement by stakeholder group				
	Farmers	Villages	District	Local universities and institutes	International societies and funding agencies
1. Co-design and research definition	Involve and collaborate	Involve and collaborate	Inform	Involve and collaborate	Inform
2. Data collection	Involve	Involve	Inform	Involve and collaborate	Inform
3. Analysis, relevancy and interpretation	Collaborate	Collaborate	Collaborate	Involve and collaborate	Inform
4. Dialogue and policy development	Empower	Empower	Empower	Involve and collaborate	Inform

researchers, farmers, villagers and district officials. The final stage involved stakeholder dialogue and policy development. The project, its impacts and outcomes were presented by the interdisciplinary research team and farmer groups to decision makers at local, regional and national and international venues and to funding agencies. Farmers, village, and district stakeholders were engaged for presentation and testimonials to document and detail impacts to policy makers facilitating policy development (Table 1).

In order to evaluate the impact of farmer's action research in the field, researcher, farmer, and extension stakeholder preferences for CA were collected pre- and post-on-farm experiments and compared using the Analytic Hierarchy Process (AHP) method. The results were communicated at international conferences for feedback on scientific rigor.

3. Study site, approach and methods

3.1. Study site

The study was conducted in the Keonjhar district of Odisha, India from 2011 to 2014. The site is in the North-Central Plateau zone of Odisha. The soil is mainly developed from colluvial-alluvial deposits in piedmont plain with soil texture ranging from sandy clay loam to sandy loam and classified as Fluventic Haplustepts (Inceptisol). The climate is hot, moist, and sub-humid tropic with average annual rainfall of 1500 mm with >75% of the rainfall received from May to September. Keonjhar has the highest marginalized tribal population in Odisha consisting of illiterate and resource poor farmers, has the greatest area under rainfed cultivation (27,580 ha), and currently faces problems of poor yield, soil erosion and land degradation due to intensive tillage practices with a poor level of agricultural management (Pradhan et al., 2015). The district's usual cropping system is local low yielding cultivars of maize broadcast during rainy season (mid-June–September) followed by mustard (*Brassica campestris*) as a post-rainy season crop (October–January) without any residue retention practice or cover crop (February to May). Through expert advice from scientists, local extension personnel, and local farmers along with baseline surveys, the tribal villages of Tentuli and Talachampei were chosen for on-farm trials. The villages were selected based on willingness to participate in the study, accessibility of field sites, and similarity with other regional tribal communities in terms of size and cultivation systems.

3.2. Study approach

3.2.1. Socio-economic survey

Baseline surveys were conducted using a random sample from 122 households in the tribal villages of Tentuli and Talachampei in Keonjhar district. The villages were selected with local partners based on their poor socioeconomic situation and the potential for improvements to their agricultural production systems. Sixty households were randomly selected from household lists of each village, representing 50% of the total population of the two villages. Data collection methods were designed to collect both qualitative and quantitative data. Primary data was collected using face-to-face interviews. Surveying took place in June and December 2010. Furthermore, the baseline data was used to construct representative maize-based production budgets to reflect the monetary and labor costs and total revenues from those systems.

3.2.2. Experimental design and research questions

This study assessed the effects of CA practices adapted for maize-based production systems in upland tribal areas of Keonjhar, Odisha, India. The experiment was managed by farmers in 46 adjacent fields, forming a single contiguous area. The trials were conducted over 3 years (2011–2014). Plots within fields were established in a randomized block design with five treatments consisting of: farmers traditional practice (FP) which was conventional tillage (plow twice) with broadcast of local variety maize (*Zea mays* L.); and four CA treatments viz., conventional tillage with sole cropped maize using line sowing of the improved maize cultivar 'Nilesh' (CT-M); conventional tillage with maize intercropped with the improved cowpea (*Vigna unguiculata* L.) cultivar 'Hariyalli Bush' (CT-M + C); reduced tillage (plow once) with sole cropped improved maize (MT-M); and reduced tillage with improved maize + cowpea (MT-M + C). Each field was considered as a blocked replicate of the treatments. In each farmer field, conventional tillage was achieved by animal-assisted plowing plots twice, while in reduced tillage plots, the plot was plowed once. Seeds were sown along lines drawn with the help of a trench hoe in CA treatments. In the intercropped plots, cowpea was sown in between maize rows in 1:1 ratio. After maize and cowpea harvest, the field was prepared for mustard (*Brassica juncea* L.) planting in the post rainy season. In the case of conventional tillage, the entire field was plowed. For reduced tillage, only the crop ridges were dismantled, leveled and planting lines demarcated. The mustard cultivar 'Athagada Local' was line sown as a cover crop in all plots where as it was broadcasted in FP plots. The crop was harvested approximately 75 days after sowing and threshing was done within the field on plastic tarpaulins, ensuring retaining of crop residues in their respective plots. The recommended chemical fertilizers applied to the crops in CA plots were indicated in Table 2 whereas FP included broadcasting of FYM depending on its availability. The fertilizer applied for maize + cowpea was based on additive series, taking into consideration 100% plant population of maize and 50% plant population of cowpea. The fertilizers were applied inline basally for the crops except maize where nitrogen was applied in three splits viz. 25% basal, 50% at first hand weeding and rest 25% at second hand weeding. No novel tools or herbicides were used in this study considering their local availability as well as purchasing power of the farmer.

The research questions investigated were cropping system productivity, profitability, soil quality and farmer preferences for CA. System productivity was measured using maize equivalent yield (MEY). Profitability was measured using partial budget analysis. Soil quality was measured using soil quality index and farmer preferences for CA treatments were measured through AHP.

3.3. Study methods

3.3.1. System productivity

Certain inputs collected from the on farm trials were used for the analysis. For measurement with a common denominator, the yields

Table 2
Details of crop varieties, spacing (cm) and fertilizer dose (kg ha^{-1}) in CA treatments.

Crops	Selected variety	Spacing (cm)	Fertilizer dose (kg ha^{-1})		
			N	P_2O_5	K_2O
Maize	Nilesh	60 × 30	80	40	40
Cowpea	Hariyalli Bush	30 × 15	20	40	20
Mustard	Athagada Local	30 × 10	40	20	20
Form of fertilizer			Urea	Single super phosphate	Muriate of potash

produced from the non-maize crops were converted to MEY using the formula below. The crop price data used was based on market prices collected by partners from Orissa University of Agriculture and Technology (OUAT) from 2011 to 2014.

$$\text{MEY}\left(\text{kg}\cdot\text{ha}^{-1}\right) = \text{Crop yield}\left(\text{kg}\cdot\text{ha}^{-1}\right) \times \text{Crop price}\left(\cdot\text{kg}^{-1}\right)/\text{Maize Price}\left(\cdot\text{kg}^{-1}\right)$$

Total system productivity over the initial 3 years of on-farm trials was estimated by analyzing the yield contributions of cowpea and mustard towards maize equivalent yield under different treatments.

3.3.2. System profitability

The profitability calculation used the partial budget analysis method that includes total variable cost, gross field benefits and net field benefits under each treatment. The variable costs included human labor costs for bullock-drawn plow used for land preparation, sowing, weeding, and harvesting and cost of inputs such as seed, fertilizer and farm yard manure (FYM). The unit of human labor was based on labor day(s) ha^{-1} and was calculated by recording the time required for each agricultural activity and converting them to labor days (8 h being equivalent to 1 labor day). The cost of labor was calculated using the minimum wage rate for the study years as per the Labor Law of the Government of India. Similarly, the time required by the bullock-drawn plow to complete the tillage practice was recorded and expressed as day(s) ha^{-1} (8 h being equivalent to 1 day). Gross field benefits were calculated by multiplying the price of maize by the maize equivalent yield where price of maize was estimated by taking the price that farmers receive for the crop when sold, and subtracting the costs associated with harvest, and sale proportional to the yield. Net benefits were calculated as the difference between gross field benefits and total variable costs.

3.3.3. Soil quality

Soil samples were collected with a soil auger in May 2011 before the implementation of the CA and in May 2014, 3 years after practicing CA. The samples were collected from 0 to 10 and 10–20 cm depths in three randomly selected sampling points for each plot. The three sub-samples from each sampling point and depth were mixed to give one composite sample for each depth class per plot. After transfer to the laboratory, the field-moist soil samples were passed through an 8-mm-pore sieve and air-dried. One part was crushed to pass a through a 2-mm-pore sieve for soil chemical analyses.

Fourteen variables representing soil physical, chemical, and biological properties were measured in order to assess the effect of CA regimes after three cropping cycles. Bulk density (BD) was measured by the core method (Blake and Hartge, 1986) while two size classes of water stable aggregates (WSA, >250 μm and 53–250 μm) were determined by using the wet-sieve method (Kemper and Rosenau, 1986). Available water content (AWC) was calculated as the difference between moisture retention of soil core samples at field capacity (−0.33 bar) and permanent wilting point (−15 bar) using a pressure plate apparatus. Total soil carbon (C) and nitrogen (N) were determined by oxidation-combustion (Costech, Inc., CHN analyzer) while soil pH was measured in a 1:2.5 soil: water suspension with a pH meter. Soluble phosphorus (Olsen P) was measured by sodium bicarbonate ($NaHCO_3$) extraction and subsequent colorimetric analysis (Olsen et al., 1954). Available potassium (K) was determined using ammonium acetate extraction followed by emission spectrometry. Soil nitrate (NO_3^- —N) and ammonium (NH_4^+ —N) were determined by extraction with 1 M KCl solution (Keeney and Nelson, 1982) followed by analysis on a Lachat automated ion analyzer. Labile carbon (C) was calculated as cumulative CO_2 efflux measured over a 28-day incubation period per gram carbon in soil. Potentially mineralizable nitrogen (PMN) was estimated as the difference between extractable soil NO_3^- —N and NH_4^+ —N at the beginning and end of the 28-day incubation.

To assess the effect of tillage, cropping system and cover crop residue on overall soil quality, measured soil physical, chemical and biological properties were taken as indicators. Further selection of a minimum data set (MDS) from the fourteen measured variables, their scoring and integration to a single index value was performed according to Andrews et al. (2002). A standardized principal component analysis was employed as a data-reduction tool in order to select MDS. The variables selected in minimum data set were ranked in ascending or descending order depending on whether a higher value was considered 'beneficial' or 'detrimental' to primary soil function which in this case is crop yield. For 'higher is better' indicators, each observation value was divided by the highest observed value such that the highest observed value received a score of 1. This was opposite for the 'lower is better' indicators such that the lowest observed value was given a score of 1. For indicators following an 'optimum is better' concept, observations were scored as 'higher is better' up to a threshold value and then scored as 'lower is better' above the threshold value. After scoring of MDS variables, weight for each indicator was assigned by its communality, using the PCA results (Li et al., 2013). The soil quality index (SQI) was calculated as

$$\text{SQI} = \sum_{i=1}^{n} (Wi \times Si)$$

where *Wi* is the assigned weight and *Si* is the indicator score of variable *i*, and *n* is the number of indicators in the MDS. Higher index scores indicate better soil quality.

3.3.4. Farmers preference survey

An AHP (Saaty, 2008) was used to explore farmers' preferences of the various CA and the criteria/objectives that the farmers used to make their decisions (Braunschweig, 2000; Dyer and Forman, 1992) (Fig. 1). First the three levels of the hierarchy were established by determining the goal of the preferred decision (Level 1: improved income), then determining the objectives/criteria on which the treatments decisions depend (Level 2: profit, labor saving, yield, and soil environmental benefit), and finally laying out the given treatments at the lowest hierarchy level (Level 3: FP, CT-M + C, MT-M, and MT-M + C). Pairwise comparison matrices were developed ensuring that each element of the higher level of the hierarchy was compared with every possible pair of the elements that were below it (i.e., goals vs. paired

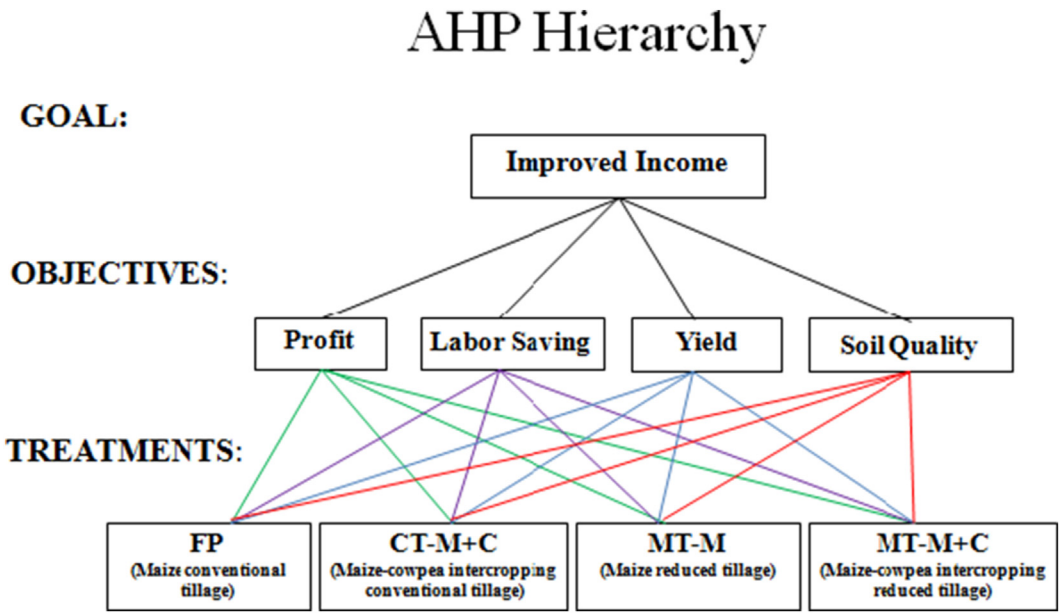

Fig. 1. An AHP diagram showing the three levels and relevant pairwise comparisons.

objectives/criteria and objectives/criteria vs. paired treatments/alternatives). Local priorities were synthesized throughout the hierarchy in order to compute the overall priorities of the treatments/alternatives (Braunschweig, 2000; Saaty, 2008) using the following equation:

$$P_l = \sum_{m=1}^{M} p_{lm} v_m \text{ with } \sum_{l=1}^{L} p_{lm} = 1 \text{ and } \sum_{m=1}^{M} v_m = 1$$

where:
P_l = final priority of project l
P_{lm} = priority of project l with respect to criterion m
V_m = weight of criterion m
$l = (l,\ldots, L)$
$m = (1,\ldots,M)$

At each site, respondents were chosen randomly from male and female household decision makers that were available and willing to participate in the study in March 2011. Afterwards, results were presented to respondents and a group meeting followed, stimulating discussion about preferences and objectives as well as scope and objectives of CA treatments. A list was made of the farmers who were willing to participate in the program. Again in May 2013, the survey was conducted among those participating farmers only (44 in number) in order to compare their preferences both before and after the implementation of CAPS.

The study is based on primary data collected from baseline and ongoing surveys, focus group discussions, and on data from farm trials. The entire data related to agronomic, soil, socio-economic was compiled and analysed through respective measures stated in the methods section. After ensuring normality and homogeneity of variance of the data, they were subjected to analysis of variance (ANOVA) and analysed for significance using appropriate F-tests (SAS Institute, 2001). Where the F-tests were significant, means were compared using Tukey's honest significant difference (HSD). Due to non-significant effect of year, pooled data over the three cropping seasons were taken into consideration for analysis of system productivity. Profit analysis was based on partial budget analysis of total crop production system productivity. Similarly, for soil parameters, soil quality index scores were calculated using mean values of soil variables.

4. Results and discussion

4.1. Farm profiles

The results of the socioeconomic survey showed the average village household family size consisted of seven members, with two to three generations per household (Table 3). Farm household incomes for 2009–2010 vary from an average of 400 USD to 1000 USD per year for families having employment in mining industry. Livestock kept in the villages includes cattle, oxen, goats, and chickens. In the district of Keonjhar, approximately 50% of households own oxen, mainly for the use of plowing. On average, there was no formal education reported in Tentuli and Talachampei. Average farm size was 1–2 ha and average yield of maize in these villages was about 2 t ha^{-1}.

The surveys also confirmed that the households in these areas are highly dependent on agriculture to sustain their livelihood, given that opportunities for off-farm employment are limited. Both the villages cultivated maize followed by mustard as their major cropping system with 40% of the surveyed population producing maize solely for household consumption and livestock feed. The remaining 60% of the population sold on average 50% of their maize output in the local market. Such dependency on maize production for both household food security and income generation indicates a demand for agricultural practices to improve maize yields

4.2. System productivity and profitability

To assess the effect of CA under local ecological and socio-economic condition, the study focused on two basic types of ecosystem services: provisional and regulatory services. Under provisional ecosystem services, performance of CA on crop yield and profitability was assessed through maize and maize equivalent yield of cowpeas and mustard. The MEY was calculated based on the yields (kg ha^{-1}) of maize, cowpea and mustard for each of the 46 farming household which took part in the on-farm trials.

All the CA treatments showed increased productivity over farmers' practice ($P < 0.05$) (Fig. 2). This might be due to higher productivity of improved cultivar along with optimum plant population due to line

Table 3
Key average farm household characteristics of the tribal villages Tentuli and Talachampei in Keonjhar, Odisha, India (2010). Values are means ± standard deviation.

Village	Household size	Farm size (ha)	Household income (USD/year)	Predominant cropping pattern	Maize yield (t ha^{-1})
Tentuli	7 ± 4	1.4 ± 0.32	400 ± 150	Maize-mustard	2.0 ± 0.43
Talachampei	7 ± 5	1.5 ± 0.51	1000 ± 200	Maize-mustard	2.5 ± 0.78

sowing and recommended dose of fertilizer application in CA treatments. Further, MT-M + C-Mu showed highest MEY which was 200% higher than FP (10,548 vs. 3450 kg ha^{-1}, respectively) but remained at par with CT-M + C-Mu. There was no yield penalty during initial years, indicating reduced tillage to be as good as conventional tillage (Pradhan et al., 2015). Further, intercropping significantly increased total system productivity not only due to cowpea as an additional yield with maize from the same plot at the same time but also their higher market price, 1.5–2.0 times that of maize.

The highest increase of total labor (140%) was reported under MT-M + C followed by mustard over FP (296 vs. 123 labor days h^{-1}) while the smallest increase was under MT-M (70%) (Table 4). Among field operations, the labor requirement for weeding and harvesting was more variable. Further, intercropping in reduced tillage had a positive impact on labor required for weeding as the cowpea intercrop covered the inter-row space quickly controlling weeds. Similarly, labor for the harvesting operation varied mainly due to the amount of production under different treatments and their post-harvest management. Even though the cost of cultivation was highest for MT-M + C-Mu, higher maize and mustard yields along with additional cowpea yield increased profit by 230% over FP (754 vs. 227 USD ha^{-1}) (Table 5).

4.3. Soil quality

It is well known that soil quality is the key to crop production and yield sustainability. The effects of soil quality on agricultural productivity are greater in low-input rain fed production systems than in highly productive systems (Scherr, 1999). Further, Govaerts et al. (2006) reported a direct and significant relation between soil quality status and the crop yield after 10 years of different tillage and residue management treatments. It also suggests that an improvement in soil quality though not immediately is reflected in crop yields but will help in achieving sustainable system productivity through better ecosystem services. In this study, the soil quality index was highest under minimum tillage combined with maize cowpea intercropping followed by mustard residue retention and lowest under farmers' practice which is conventional tillage with broadcasted maize and no residue retention conditions (Fig. 3). Though, application of recommended dose of fertilizer in CA might have contributed towards the treatment effects on soil quality however, increased SQI value under MT-M + C-Mu within a short period of three years suggests additional benefits of CA on top of fertilizer contribution (Fig. 3). Though minimum soil quality was seen under FP, further research is needed to see whether the trend remains consistent in long term or not. Moreover, this assessment of soil quality during early phases of conservation practice provided more insight into management induced changes thereby relating to their possible beneficial effects in future.

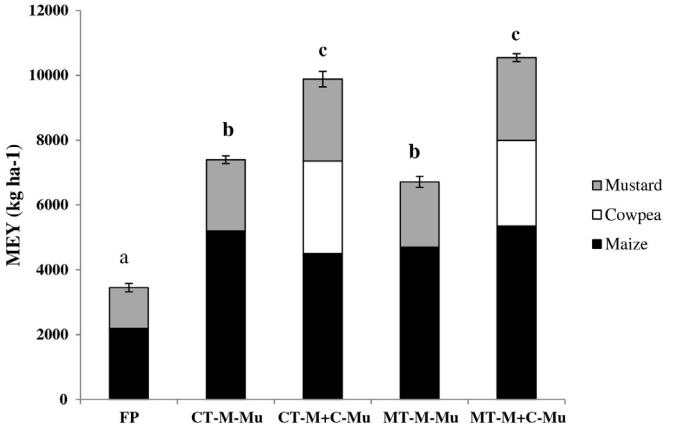

Fig. 2. Effect of treatments on system productivity in terms of maize equivalent yield (MEY) in kg ha^{-1}. Bars are mean values ± one standard error. Bars of MEY followed by different letters are significantly different at $P < 0.05$ according to Tukey's HSD test. FP: farmers' practice, CT: conventional tillage, MT: reduced tillage, M: maize, C: cowpea, and Mu: mustard. Market price of the crops were used for calculating the MEY (maize @ $ 0.16 kg^{-1}, cowpea @ $ 0.30 kg^{-1} and mustard @ $ 0.45 kg^{-1} [market survey and feedback from farmers]).

4.4. Farmers' preferences

The Analytic Hierarchy Process (AHP), both before and after the on-farm trials, documented that farmers shifted their preferences after the on-farm trials. In this study, farmers weighed importance on the objectives/criteria for improved income prior to on-farm trials as follows: yield (0.329), profit (0.274), soil (0.213) and labor (0.184), with the sum totally to one (Fig. 4). Labor saving was the least important relative to the other objectives/criteria. This could be due to underemployment of household labor in general. Moreover, households' dependency on off-farm employment for additional income occurs during the period of March–June and therefore the cropping seasons (July–February) has sufficient labor availability in the study site. Further, from a biophysical standpoint, farmers may have sought soil enriching practices in order to increase agricultural productivity, and thus placed a greater preference for CA treatments that would offer immediate gains (yield) over long-term gains (soil environmental benefit). After 2 years of farm trials, farmers' weights on criteria changed (Fig. 4). To be specific, farmers in this study shifted their criteria weights following on-farm trials, placing the criteria of soil environmental benefit (0.426) over higher yield (0.316). Without ready access to technology and information, farmers in the study area rely on observation and traditional knowledge to assess the impact of an agricultural practice. Astute observation and experience working the land might have given the farmers an invaluable perspective on the likelihood of CA to improve soil quality.

In terms of CA treatments before on-farm trials, farmers in this study indicated equally strong preference for MT-M + C (0.347) and CT-M + C (0.366), compared to FP (0.141) and no intercropping trials (Fig. 5). As indicated, farmers had a preference for treatments that included cowpea because of its higher value in the local market (compared to maize) and nutrition to the family and the soil leading to increased yield. The higher market price of cowpea can be explained as it was not grown locally rather occasionally bought from faraway larger markets based in the cities. Also they had never intercropped maize with a legume before and, through disseminated CA information, had positive expectations that along with availability of cowpea for household consumption and local market, increased soil nutrients would further increase yield and profit. Farmers' preferences (before/after) clearly highlighted their economical preferences towards treatments that led to greater yield and net profits (i.e., CT-M + C and MT-M + C). Yield and profits are different as most are subsistence farmers who grow mainly for household consumption and sell any remaining surplus. This is more of the case for maize as cowpea is grown as a cash crop. Post on-farm trial treatment preference results are slightly different than before the on farm trials. Before CA treatment interventions, farmers preferred CT-M + C. After practicing CA for 2 years,

Table 4
Total variable cost incurred for farmers' practice and conservation agriculture (CA) practices.

Agricultural operations		FP			CT-M-Mu			CT-M + C-Mu			MT-M-Mu			MT-M + C-Mu		
	Price per unit ($)	No. of units		Total cost ($ ha^{-1})	No. of units		Total cost ($ ha^{-1})	No. of units		Total cost ($ ha^{-1})	No. of units		Total cost ($ ha^{-1})	No. of units		Total cost ($ ha^{-1})
		M	Mu		M	Mu		M + C	Mu		M	Mu		M + C	Mu	
a) Land preparation																
• Bullock plowing (day(s))	2.50	5	2	17.50	5		12.50	5		12.50	2		5.00	2		5.00
• Labor day(s)	2.50	20	8	70.00	25	10	87.50	25	10	87.50	15	10	62.50	15	10	62.50
b) Sowing																
• Seed																
Maize	2.24	—	—	—	15	—	33.60	15	—	33.60	15	—	33.60	15	—	33.60
Cowpea	7.59	—	—	—	—	—	—	10	—	75.90	—	—	—	10	—	75.90
Mustard	0.79	—	—	—	—	7.5	5.93	—	7.5	5.93	—	7.5	5.93	—	7.5	5.93
• Fertilizer																
DAP	0.22	—	—	—	87	43	28.60	130	43	38.06	87	43	28.60	130	43	38.06
Urea	0.09	—	—	—	140	70	18.90	145	70	19.35	140	70	18.90	145	70	19.35
MOP	0.11	—	—	—	65	43	11.88	106	43	16.39	65	43	11.88	106	43	16.39
• Labor day(s)	2.50	7	10	42.50	10	5	37.50	15	5	50.00	10	5	37.50	15	5	50.00
c) Intercultural operations (labor day(s))																
• First weeding, top dressing	2.50	30	10	100.00	40	20	150.00	40	20	150.00	50	20	175.00	45	20	162.50
• Second weeding and top dressing	2.50	10	—	25.00	15	—	37.50	10	—	25.00	25	—	62.50	10	—	25.00
d) Harvesting & threshing																
• Labor day(s)	2.50	18	10	70.00	50	50	250	115	45	400.00	30	45	187.50	126	50	440.00
Total labor days (ha^{-1})		123			225			285			210			296		
Total variable cost ($ ha^{-1})				325.00			673.9			914.23			628.91			934.23

All prices in $ indicate US dollar and 1US Dollar equals to an average of 55 Indian National Rupees (during the crop harvest periods of 2011–2014). FP: farmer practice, CT: conventional tillage, MT: reduced tillage, M: maize, C: cowpea and Mu: mustard.

farmers preferred MT-M + C, the most innovative of the four treatments providing the best optimal outcome compared to existing conventional farmer practices.

5. Implications and policy development

Agriculture in developing countries primarily focuses on finding a sustainable agricultural technology that meets the demands of smallholder farmers while maintaining or improving soil fertility. Though there is no universal strategy to end challenges to food security and rural poverty but it was evident from the study that combining and simultaneously applying location-specific and low-input conservation agriculture practices such as reduced tillage, diversified cropping system through maize + cowpea coupled with residue retention of mustard helps in optimizing resource use efficiency and maximize productivity of traditional smallholder farming systems. Given the use of familiar crops and technologies and the magnitude of yield and income improvements, the AHP output infers that CA with reduced tillage and intercropping should be acceptable and attractive for smallholder farmers in the area. Moreover, the ability to simultaneously increase yield, diversify crop production and improve soil quality should support a move towards sustainable intensification of crop production to meet future household income and nutritional needs amidst climate variability. Additionally, increased profitability within the three years of this study suggests economic empowerment of tribal farmers in order to afford the higher cost CA treatments in future. Farmers have testified to the merit of CA and the Odisha district government has subsequently provided input support for scaling up to other farmers in the area. Furthermore, government schemes like fertilizer subsidy program, soil health card will help timely availability and affordability of fertilizers as well as their balanced application in an integrated manner. This type of understanding of farmers' preference of innovative practices

Table 5
Partial budget analysis of farmers' practice and conservation agriculture (CA) practices.

Treatment	Cost of cultivation (USD ha^{-1})[a]	Total return (USD ha^{-1})[b]	Profit (USD ha^{-1})[c]
FP	325	552	227
CT-M-Mu	674	1206	532
CT-M + C-Mu	914	1500	586
MT-M-Mu	629	1084	455
MT-M + C-Mu	934	1688	754

FP: farmer practice, CT: conventional tillage, MT: reduced tillage, M: maize, C: cowpea and Mu: mustard.

[a] Cost of cultivation indicates the total variable cost incurred under farmers' practice and other CA practices (Table 4).

[b] Total system productivity in terms of MEY was multiplied by the market price to get the total return under treatments (maize @ $ 0.16 kg^{-1}).

[c] Profit was calculated by subtracting cost of cultivation from total return.1US Dollar equals to an average of 55 Indian National Rupees (during the crop harvest periods of 2011–2014).

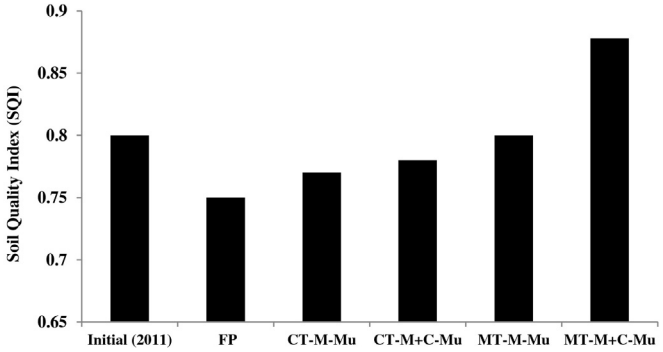

Fig. 3. Effect of treatments on soil quality after three years of cropping cycle (2011–2014). FP: farmers' practice, CT: conventional tillage, MT: reduced tillage, M: maize, C: cowpea, and Mu: mustard.

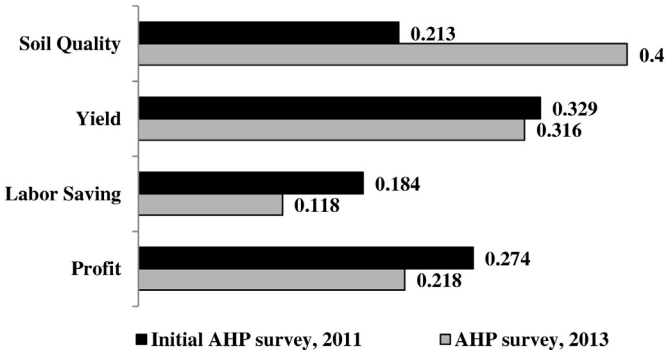

Fig. 4. Farmers' preferences (weights) of objectives with respect to the goal of improved income.

can provide the confidence and necessary information for effective research, extension, and government intervention. As a by-product of the transdisciplinary approach, policy and government decision-makers receive information not only about the implicit weights that are placed on the various evaluation criteria but about the consistency of these across villages as well. This leads to improved communication and a clearer understanding and consensus among members of decision-making groups, allowing them to become more committed to the programs selected. As research extension projects and government intervention often come with limited monetary fund and timelines, integrating farmers' preferences into the initial project planning phase followed by their agro-ecological and socioeconomic evaluation will be more effective and beneficial for future outcomes.

Availability of trained human resources at ground level is one of the major limiting factors in adoption of CA. Policy support for capacity building in CA is needed and should be supported at all levels. Incorporating the principles of CA into curricula from primary school to the university will increase the overall population familiarity with the concept, but can serve as an integrating topic for sustainable resource management.

Further, institutionalizing CA into relevant government ministries and departments, and regional institutions will enhance the sustainability of the technology. Local, national and regional policy and decision makers could spearhead and support the formulation and development of strategies and mechanisms for scaling up the technology. CA integrates well into interventions such as improved seed, fertilizer, tillage, and draft power support programs as a means to enhance agricultural productivity and food security for smallholder farmers. The success of this study and the future success in introducing CA in other areas, lies in undertaking a participatory transdisciplinary approach involving scientists, farmers, extension agents, policy makers and stakeholders in the private sector.

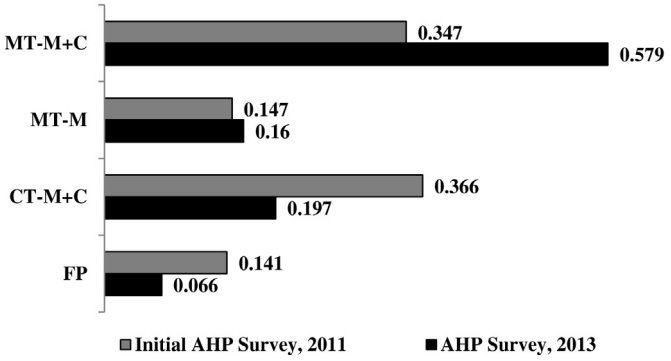

Fig. 5. Farmers' preferences (weights) of treatments with respect to the goal of improved income. FP: farmers' practice, CT: conventional tillage, MT: reduced tillage, M: maize, and C: cowpea.

6. Conclusion

Conservation agriculture practices are beneficial over the traditional practices in terms of household income, food security, and natural resource management and utilizing a transdisciplinary approach that engaged stakeholders ensured that farmers and officials understood the costs and benefits of CA. Moreover, having farmers directly participating in the co-design and actively engaged in field experiments, the farmers experience firsthand the impact of CA treatments. The AHP pre- and post-on-farm trial surveys demonstrate that stakeholders converge in their preference for the same CA after participating and witnessing the outcome of the field trials. The preferred treatment was a reduced tillage maize intercropped with cowpea system which has provided the highest profit and greater enhancement of soil quality compared to traditional farmer practices (Pradhan et al., 2015). Farmers outside the selected villages in the Keonjhar district are now adopting the reduced tillage maize cowpea intercrop system with the buy-in of the district government. This scaling up is a step towards using climate smart CA to provide resilience to the village communities.

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